

## Improving the Accuracy of the SeaUV Algorithms in Dark Marine Waters

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### LONG-TERM GOALS

Our long-term objective is to develop a robust set of algorithms for the global ocean to provide accurate surface UV attenuation and CDOM retrieval from remotely sensed ocean color for use in optical, photochemical, and photobiological investigation.

### OBJECTIVES

The central objective of this project is to generate new, high quality optical data sets for a variety of darker coastal systems to be used in evaluating the SeaUV algorithms and retraining them for accurate use in the highly variable optical conditions typical of the nearshore environment.

### APPROACH

Previous ONR funding in our lab produced two improved and ready-to-use algorithms (SeaUV and SeaUV<sub>C</sub>) detailed in Fichot (2004) and Fichot et al. (2008). These algorithms are used for estimating  $K_d(320-490)$  and  $a_g(320)$  from measurements of spectrally resolved remote sensing reflectance,  $R_{rs}(\lambda)$ . Our general approach for this project is to collect new in situ optical data sets for near coast and inshore dark waters, apply the SeaUV algorithms to this new data set for evaluation of current predictive capability, and incorporate these new data into the training data set for evaluation of improved predictive capability using new 'dark trained' algorithms. The final product will be a single model that will predict  $K_d(\text{UV})$  and  $a_g(\lambda)$  from ocean color in optical domains ranging from the clear open ocean to the dark waters found in close proximity to the coast. We will then apply these trained algorithms to independent data sets where possible for validation.

*Approach to Fieldwork:* We collect simultaneous *in situ* measurements of  $Lu(\lambda)$ ,  $K_d(\lambda)$  and  $a_g(\lambda)$  in the dark waters found near the coast, focusing efforts around the UGA Marine Institute (UGAMI) on Sapelo Island, GA (see Figure 1). Past ONR funding has provided the Satlantic<sup>®</sup> instruments to collect high quality UV-Vis data for use in the SeaUV algorithms: a Satlantic<sup>®</sup> MicroSAS ocean color buoy (2 sensors for below-surface multispectral visible upwelling radiance: wavebands = 412, 443, 490, 510, 555, 670 and 683nm) is deployed adjacent and coincident with a Satlantic<sup>®</sup> Micropro free fall profiling radiometer (2 sensors for below-surface multispectral UV-Vis downwelling irradiance: wavebands =

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305, 325, 340 380, 412, 443, 490, 555nm) and a reference radiometer (2 sensors for above-surface multispectral UV-Vis downwelling irradiance: wavebands = 305, 325, 340 380, 412, 443, 490, 510, 555, 670 and 683nm). Water samples for spectrophotometric determination of  $a_g(\lambda)$  and DOC are collected simultaneously with all survey optical data.

We seek opportunities to deploy our Satlantic systems in as many inshore and near-coastal waters as possible using “cruises of opportunity” in order to supplement the southeastern US data set, thus adding potentially different optical domains to the training set. Last year an opportunity for multiple seasonal cruises in the Gulf of Mexico allowed expansion of our optical data set to nearshore stations along onshore-offshore transects in the gulf. This year we participated in the last of this 5-cruise effort. These data is still undergoing QA&QC and analysis to examine compatibility with simultaneous optical data collected in conjunction with Steve Lohrenz’s Satlantic Hyperpro at the same sites.

*Approach to Data Analysis:* The new *in situ*  $Lu(\lambda)$  data collected in dark coastal waters is processed with the SeaUV and SeaUVc algorithms to generate modeled  $K_d(\lambda)$  and  $a_g(\lambda)$  estimates for the region. The measured *in situ*  $K_d(\lambda)$  and  $a_g(\lambda)$  data is then compared to the model with statistical analysis following that of Fichot et al. (2008). The new ‘dark water’ optical data sets are then added to the SeaUV training set, the model is retrained, and new estimates are re-evaluated for performance in all optical domains. As we accumulate sufficient dark water *in situ* UV optical data to make the approach statistically valid, we evaluate the use of data subsets to train type-specific versions of SeaUVc. For example, we are examining the effectiveness of constraining the training set to include only spectral data with  $Lu(412)$  values from highly absorbing water and exploring the development of algorithms specific for use in near shore systems. As new data, both from different seasons (and terrestrial flow patterns) and from different locations are obtained, we explore how these new sets effect both specific and overall performance of the SeaUV algorithms. A continued statistical examination of both the “blue water” and the “dark water” accuracy is repeatedly performed as the training set is seeded with more dark water data. The result is a more robust optical model that uses ocean color to estimate UV radiation fields in the surface ocean for use in photochemical and photobiological process models. This translates to better predictive capability of CDOM dynamics in nearshore waters.

*Approach to Validation and Prediction:* Simply stated, this involves mining existing published data and optical databases and seeking out other sources of optical data sets (unpublished with collaboration) for ‘dark’ water to provide an independent test of SeaUV performance and future incorporation into the SeaUV training set. Because we systematically incorporate our new dark water data into the training set for improved SeaUV/SeaUVc estimates, the identification of other data is critical to independent varification of the models performance.

## WORK COMPLETED

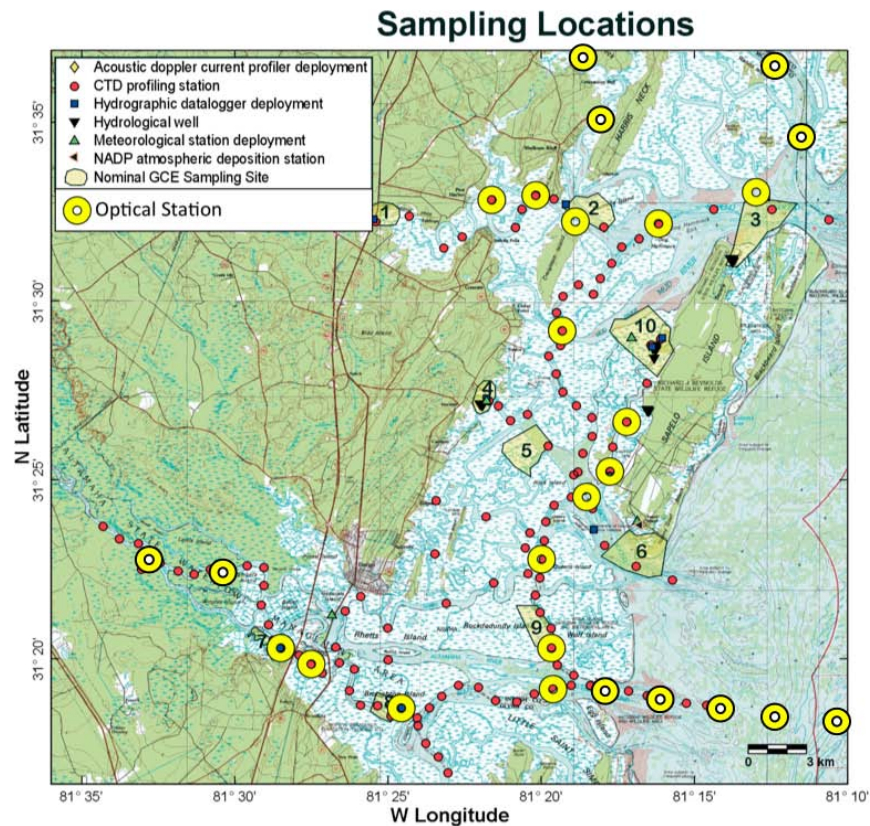
- We staged for, and participated in another cruise (bringing the total to 5) to the northern Gulf of Mexico, obtaining data sets from new optical stations for use in testing and training the SeaUV/SeaUVc model against  $K_d$  and  $a_g$  *in situ* measurements.
- We obtained a third set of optical data ( $K_d(UV)$ ,  $a_g$ ) for additional stations located around Sapelo Island, GA, including a new offshore transect to Grey’s Reef.

- New dark water data was used to evaluate previous retraining of the SeaUV/SeaUVc and we continued the sequential addition and retraining of the model.
- We designed, constructed, tested and deployed a new frame for our Satlantic OCS system that improves our ability to gather data in shallow dark systems.
- We continued training of new graduate students in the field setup and operation of our Satlantic gear and the MatLab programming required to analyze field data and retrain the SeaUV code.
- Two graduate students participated in the Ocean Optics XX meeting and a short course on IOP & AOP measurements.
- We continued to refine, comment, and generally detail the steps in using the SeaUV algorithms and related programs to increase usability by others following Fichot's departure from UGA.

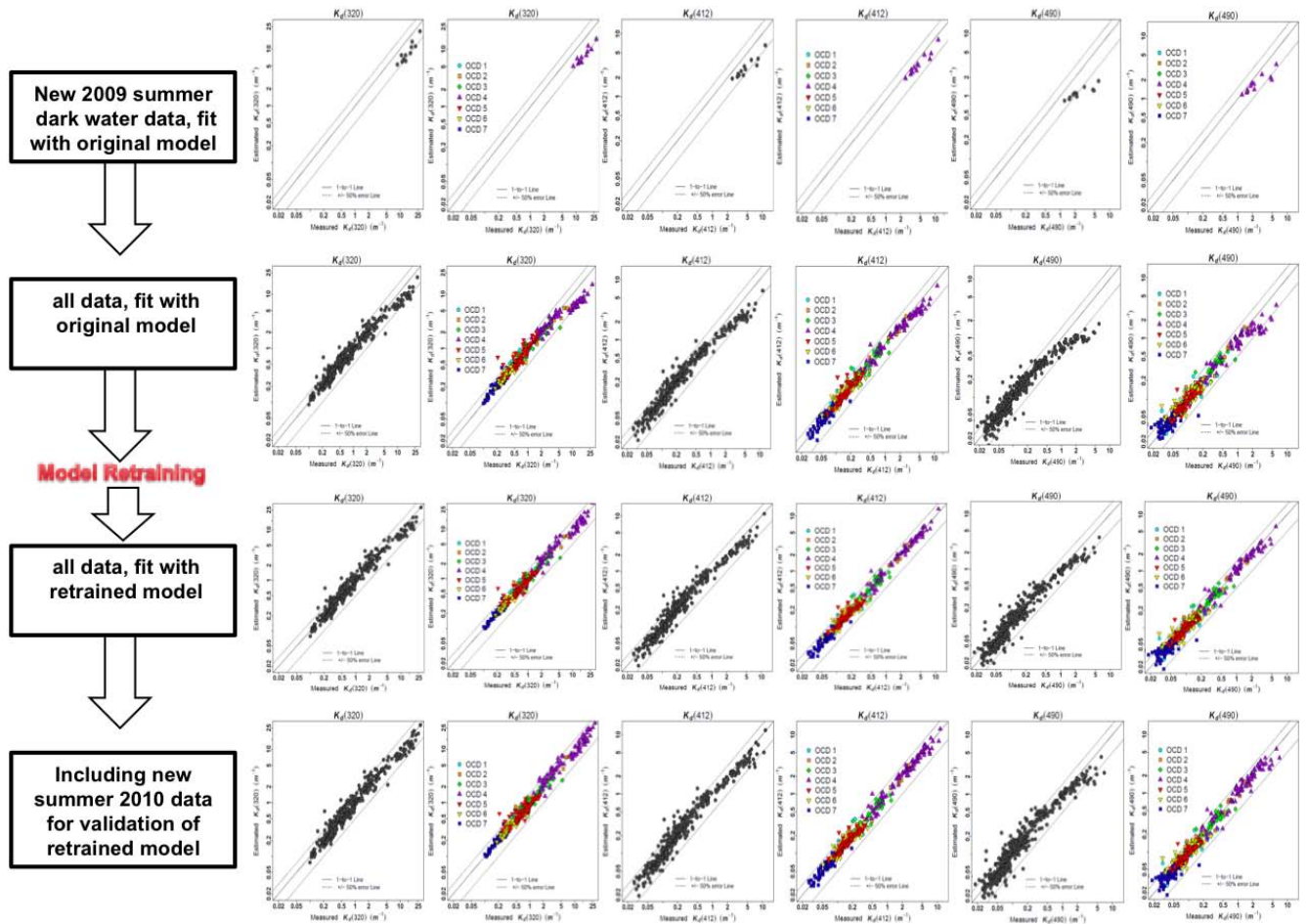
## RESULTS

The main result for this year has been collection of more field data for coastal and inshore waters with surveys of DOC, CDOM, UV attenuation and water-leaving radiance. We continued to build the data set for the dark waters surrounding Sapelo Island, GA, working in conjunction with the GCE-LTER (Georgia Coastal Ecosystem – Long Term Ecological Research) program (Figure 1). We completed our cruise collaboration with the GulfCarbon project, an NSF funded seasonal study of pCO<sub>2</sub> (Dr. S. Lorenz; PI). We recently participated in a two-day workshop with the GulfCarbon group to identify areas of collaboration for publications.

The retraining exercise that added new 'dark water' data to the SeaUV/SeaUVc model resulted in increased accuracy for coastal waters. Figure 2 (below) shows representative results for modeled K<sub>d</sub> values. These same comparisons have been done for all wavelengths and for CDOM estimates. Continued addition of new data in the coming award period, by re-sampling around Sapelo Island in different seasons, will build confidence in application of the model to varied optical environments. A full statistical evaluation of the resulting new model parameters that work better for dark water will be concluded once our final cruise data is incorporated.



**Figure 1. Sampling sites around Sapelo Island, GA [A navigational map of the Sapelo Island and vicinity with sampling sites used by the Georgia Coastal Ecosystem – Long Term Ecological Research project located; hundreds of red circles strung from the mouth of the Altamaha River, running behind Sapelo Island through the Intercoastal Waterway to the upper reaches of Sapelo Sound north of the island = GCE-LTER CTD stations, 15 yellow circles distributed more sparsely over this same area = our optical sampling sites; all optical sites are in tidal creeks and sounds.]**



**Figure2. Flow chart with data panels for the retraining of the SeaUV and SeaUVc remote sensing model with incorporation of new dark water optical data. [A 6 x 4 grid of figures that shows the correlation between the SeaUV (columns 1,3,&5) and SeaUVc (columns 2,4,&6, colored to match optical domains) model output for  $K_d$  on the y-axis and the measured in situ  $K_d$  data on the x-axis plotted against a 1:1 ratio line. Relationships for  $K_d$  at 320nm, 412nm, and 490nm are shown in paired columns 1&2, 3&4, and 5&6 respectively. Progressing from top to bottom, row 1 shows data for the 2009 dark samples and the significant overestimation of the original model to fit these dark samples. Row 2 shows the 2009 data with all other data in our training set for context. Row 3 shows the model fit to all data, including the 2009 dark water set, after retraining the models by allowing new principal components to be determined from the whole training set that includes the 2009 dark water data. This shows significant improvement in estimates for  $K_d$ s above about  $5 \text{ m}^{-1}$  at 320nm. The SeaUVc model with cluster analysis included performs better than the SeaUV model based on principal components alone. The bottom row shows the retrained models' improved ability to fit the new 2010 dark water data set for  $K_d$ . Again with SeaUVc performing better than SeaUV.]**

By expanding our validation data to the northern GOM, we will increase the confidence for extrapolation of the 'dark water trained' SeaUV/SeaUVc model to the transition from dark tidal inlet domains through the nearshore waters to coastal and blue systems. All data have been collected, correlated, and QA/QC analysis is underway. All optical profiles from the GOM have been examined



and new in-house MatLab code has been written to add the choice for calculation of  $K_d$  over a discrete water depth interval (rather than for one optical depth) to accommodate the dark freshwater lenses found around the outflow of the Mississippi River.

The results from this years field effort represent an ongoing refinement of the SeaUV/SeaUVc models. Miller's research group, while currently without a technician, includes 4 graduate students (one supported by ONR) that now use ocean optics as some component in their thesis research. None came to the program with any ocean optics training. A significant result from this award has been, and continues to be, an introduction and training of students with biological and chemical backgrounds to the cross-disciplinary opportunities offered by collaboration with the optical community. All have had the opportunity to participate in gathering onboard optical data with the ONR funded gear. This has served as an excellent training experience and sets up continued development of expertise in the field. Cedric Fichot, Miller's former technician, is still involved in training, instrument setup, operation, data communication, instrument testing, etc. Significant strides in training the entire group in field deployment of optical instruments have been made. The SeaUV/SeaUVc Matlab algorithms are available to the student group and all are learning the specifics of optical data analysis.

## **IMPACT / APPLICATIONS**

The SeaUV/SeaUVc model has proved to significantly improve our ability to estimate UV optical properties and CDOM dynamics in the ocean and is applicable to all marine environments including both optically shallow and deep situations, areas of high productivity and particle loads, open ocean, coastal and estuarine waters. New work on dark, coastal waters has improved this performance to a level that detailed variability of dynamic inshore areas can be better observed. Understanding of the variability in CDOM will produce better models for photochemical distributions. Better quantification of CDOM will allow better corrections for CDOM in chlorophyll algorithms and characterization of the UV light field in the ocean. Associated algorithms developed for use with SeaUV that account for cloud affects on modeling UV scalar irradiance in the ocean will prove useful to all fields studying the biogeochemical role of UV in the ocean (e.g. Fichot and Miller, 2010).

## **RELATED PROJECTS**

This ONR project to refine and apply SeaUV/SeaUVc to the evaluation of UV optics and CDOM dynamics in dark waters will benefit from collaboration with a funded NASA project (Miller, PI) to use these same models to examine photochemical carbon cycling in the south Atlantic bight off the coast of the S.E. United States. A Georgia Sea Grant (NOAA) project (Miller, PI) examines relations between ocean color and DOC in dark water for carbon export models will also be synergistic with this project. An NSF funded project to examine photochemistry in the northern Gulf of Mexico (Benner, U. South Carolina, PI) has provided access to cruise opportunities.

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Fichot C. G., and W. L. Miller (2010) Quantifying marine photochemical fluxes using remote sensing: a monthly, global, depth-resolved climatology of carbon monoxide (CO) photoproduction. *Remote Sensing of Environment*, 114; 1363–1377.

## **PUBLICATIONS**

Fichot C. G., and W. L. Miller (2010) Quantifying marine photochemical fluxes using remote sensing: a monthly, global, depth-resolved climatology of carbon monoxide (CO) photoproduction. *Remote Sensing of Environment*, 114; 1363–1377.